

# Efficient Electron Beam Deposition for Repetitively Pulsed Krypton Fluoride Lasers

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**Abstract.** We have demonstrated that we can significantly increase the electron beam transmission efficiency through a pressure foil structure (hibachi) by segmenting the beam into strips to miss the hibachi support ribs. In order to increase the electron beam transmission, the cathode strips are adjusted to compensate for beam rotation and pinching. The beam propagation through the hibachi has been both measured and simulated with 1-D and 3-D codes.

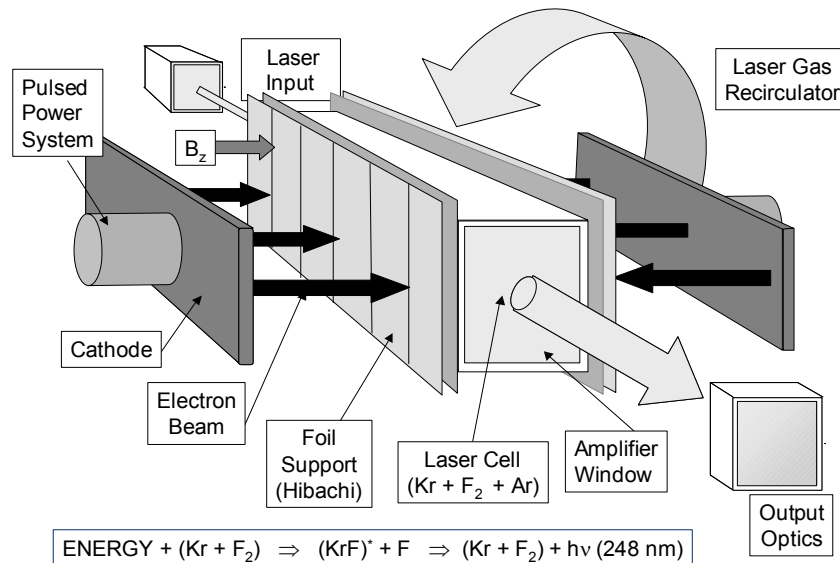
## INTRODUCTION

Electra is a repetitively pulsed, electron beam pumped krypton fluoride (KrF) laser that will develop the technologies that can meet the Inertial Fusion Energy (IFE) requirements for durability, efficiency, and cost. The Electra laser is pumped with two opposing electron beams each with parameters of 500 kV, 100 kA, and with a 100 ns flat-top pulse duration. They are emitted from 27 x 97 cm<sup>2</sup> cathodes in a vacuum diode that is immersed in an external magnetic field of 0.14 T (about 2.5 times the beam self-field). The repetition rate is 5 Hz. Fig. 1 shows the key components of a KrF laser. They include the pulsed power driver, cathode, hibachi, laser cell, gas recirculator, and optical components. As part of the program we must develop a long life, efficient, foil support structure.[1,2] The e-beam propagates through a hibachi structure, which supports a thin foil that isolates the vacuum diode from the high-pressure (>1 atm) laser gas. The ultimate goal for a full-scale 750 kV system is an energy transmission efficiency of 80% into the laser gas during the flat-top portion of the diode pulse. This paper describes hibachi developments on Electra at 500 kV that are used to benchmark simulation codes. These codes are then used to understand the complex beam physics in the diode and to predict the efficiency for a full-scale system.

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## ELECTRON BEAM TRANSMISSION INTO LASER CELL

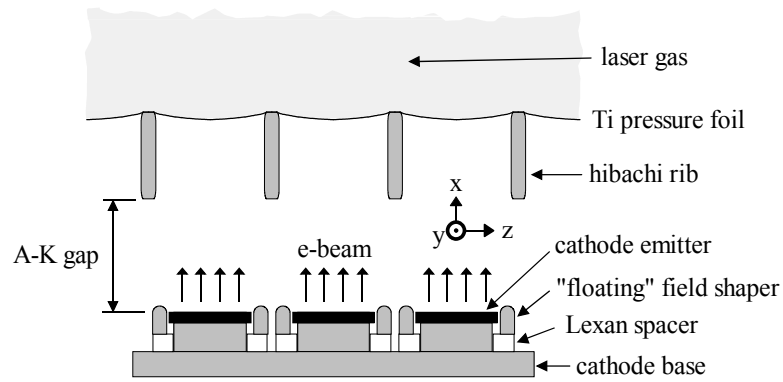
One of the key challenges for a long-lived KrF laser system is the development of a hibachi that allows reliable and efficient injection of the electron beam into the laser gas. It is obvious that to maximize transmission efficiency the electron beam needs to be segmented so that it will miss the hibachi ribs. Fig. 2 shows the basic configuration of the diode. The hibachi ribs are 5 mm in width and 28 mm deep, and they are spaced 4 cm apart. For gas deposition measurements, the laser cell, 30 cm in depth, is filled with Krypton at 1.2 atm, which stops about 99% of 500keV electrons. The cathode consists of 24 strips, each 25 mm in width, and they are placed at an A-K gap of 37.5 mm. Electron beam halos of each strip cathode have been eliminated with "floating" electric field shapers.[3] Instead of preventing electron emission from a field shaper as is standard practice [4], the field shaper is electrically isolated from the cathode, and its capacitance and charge are minimized. Therefore, a floating field shaper should not emit significant currents unless the cathode plasma expands and electrically connects the field shaper to the cathode. The "floating" field shaper concept has been tested under repetitive operation at 1 pulse per second for 3000 shots at 500 kV, with an A-K gap of 42 mm, and 160 ns FWHM pulse duration. The field shaper did not show any visible surface damage.



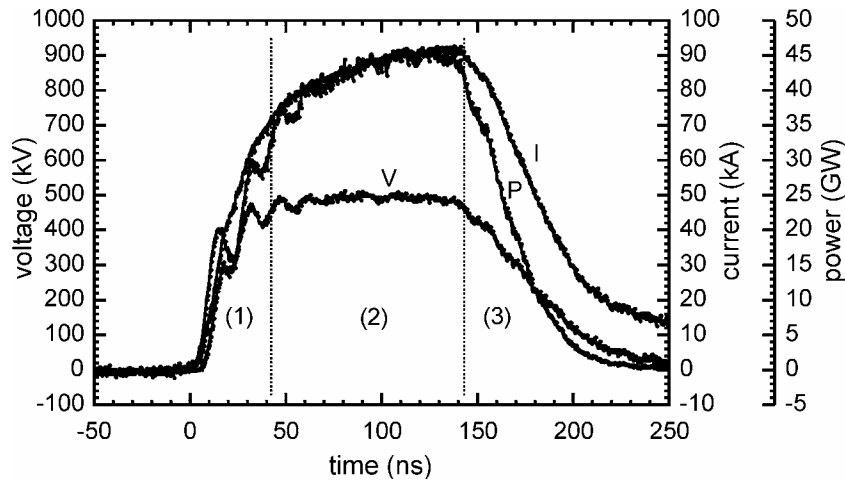
**FIGURE 1.** Key components of a krypton fluoride (KrF) laser.

The high energy transmission efficiency was achieved with two innovations: 1) eliminating the anode foil on the diode side of the hibachi structure, and 2) patterning the electron emitter into strips so the beam “misses” the hibachi ribs. While these are conceptually simple, they are difficult in practice: Eliminating the anode results in highly non-uniform electric fields, and the beam rotates and shears due to its

interaction with the applied magnetic field. Thus the cathode strips need to be “counter-rotated” so the beam will be propagating parallel to the ribs when it gets to the hibachi. The cathode strips were rotated by  $6^\circ$  and the strip-to-strip spacing increased by 0.5 mm compared to the hibachi rib-to-rib spacing to compensate for beam pinching. Typical diode voltage and current waveforms are shown in Fig. 3. During the rise, 100 ns flat-top, and fall time of the pulse, 0.7 kJ, 4.2 kJ, and 1.2 kJ are measured in the diode, respectively. The energy deposited in the gas was determined with a Baratron that detects the pressure rise in the laser cell. 1-D Tiger simulations showed that the rise and fall of the beam contribute 25% and the flat-top 75% of the energy in the laser cell.



**FIGURE 2.** Diode configuration with 28 mm deep hibachi and 25 mm wide strip cathode with “floating” field shapers. The A-K gap is measured from the cathode emitter surface to the hibachi front surface.



**FIGURE 3.** Diode waveforms: voltage, current and power are labeled V, I, and P, respectively. The diode energy is 0.7 kJ during the rise (1), 4.2 kJ during the 100 ns flat-top (2), and 1.2 kJ during the fall (3) of the pulse.

Measurements showed that the energy transmission efficiency, defined as the ratio of the deposited energy divided by the beam energy, is 67% during the flat-top portion of the pulse, at a diode voltage of 500 kV and with a 2 mil (50  $\mu\text{m}$ ) Ti pressure foil in a configuration as shown in Fig. 2. 1-D simulations without hibachi ribs (e.g., simulation considers e-beam, 2 mil Ti foil, and laser gas only) predict a transmission efficiency of 72%. These results show that the segmented e-beam propagates efficiently between the hibachi ribs with only minor losses, thus, patterning the beam imitates operation of a nearly “rib-less hibachi”.

3-D LSP [5] simulations, which include the actual diode geometry, external magnetic field, hibachi ribs, and backscattering, showed that the transmission efficiency can be increased to 74% for a 500 keV beam by decreasing the thickness of the Ti pressure foil from 50  $\mu\text{m}$  to 25  $\mu\text{m}$ . Accounting for the thicker 50  $\mu\text{m}$  pressure foil used in the experiments, the predicted efficiency would be 68%, or quite close to the experimentally observed 67%. A shallower hibachi with a rib depth of 13 mm instead of 28 mm will further increase the transmission efficiency. This new hibachi, which is currently under construction, will create a more uniform electric field at the anode, and thus, minimize e-beam spreading losses. More importantly, preliminary simulations showed that the ultimate goal of >80% hibachi efficiency is achievable at in a full-scale (750 keV) system.

## SUMMARY

Measurements and simulations show that the electron beam can propagate efficiently through the hibachi. This is accomplished by patterning the electron beam into strips and by operating the diode without an anode foil, i.e., the hibachi ribs serve as an anode. 3-D simulations agree well with the experiments performed at 500 kV and with a 50  $\mu\text{m}$  pressure foil. The energy transmission efficiency can be further increased by changing the thickness of the pressure foil to 25  $\mu\text{m}$  and by using shallower hibachi ribs.

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